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Minimum dopant levels needed to measure the ^{13}N and ^{41}Ar produced in a direct drive exploding pusher capsule at the National Ignition Facility

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ABSTRACT

We present a simple method for determining the required level of dopant into the DT gas of a National Ignition Facility capsule, in order to ensure that the products from nuclear transmutation of the dopant will be detectable at the Radiochemical Analysis of Gaseous Samples facility.

The Los Alamos Radiochemistry program for the National Ignition Facility is developing diagnostics to study hydrodynamical mixing in high-Z shell designs, such as the Double Shell and Pusher Single Shell designs. For this we plan to compare alpha-induced nuclear reactions with knock-on deuteron-induced nuclear reactions, and the reactions of choice are ^{10}B(α,n)^{13}N and ^{79}Br(d,2n)^{79}Kr. The physics relating alpha-induced and KO deuteron-induced reactions to hydrodynamical mix is discussed in [1,2]. The Radiochemical Analysis of Gaseous Samples (RAGS) apparatus [3] will be used to collect and assay the ^{13}N and ^{79}Br products from these reactions. As part of the experimental development of these two diagnostics, we are quantifying the RAGS collection efficiency of ^{13}N and ^{79}Kr using direct drive exploding pusher capsules that are doped with nitrogen or krypton. The first of these shots will involve doping a DT capsule with nitrogen and measuring the amount of ^{13}N produced in the ^{14}N(n,2n)^{13}N reaction. By co-doping the DT gas with argon, we can use the ^{40}Ar(n,γ)^{41}Ar reaction to calibrate how many ^{14}N(n,2n)^{13}N reactions took place. The ^{41}Ar collection efficiency is much easier to estimate than that of ^{13}N because of the noble gas nature of argon.

In the present note, we compute the number of atoms of dopant that must be loaded into the capsule in order to make a robust measurement of ^{13}N and ^{41}Ar at RAGS. For this purpose, we assume that the imploded burning capsule is uniformly burning and spherical, with a radius R. These assumptions are not correct, but they allow us to obtain an analytic expression for the number of product atoms in terms of the number of initial dopant atoms. Also, as seen below, we double our spherical estimate in order to error on the safe side.

For a uniformly burning spherical capsule the number of atoms produced in any nuclear reaction, N_p, is related to the number of dopant atoms, N_d, by,

$$N_p = N_d N_{14} \sigma \frac{16\pi^2}{36} \frac{1}{R^2} ,$$

where N_{14} is the total 14 MeV neutron yield and σ is the cross section for the process. The 14 MeV cross sections for the ^{14}N(n,2n)^{13}N reaction is 5.48 mb, and that for ^{40}Ar(n,γ)^{41}Ar reaction is 0.45 mb. The detection of ^{13}N and ^{41}Ar at RAGS both require that 10^6 atoms be produced in the capsule. For the radius of the burning capsule, we assume R=73 μm. This is based on the NIF shot

N170112-004, which was doped with 0.05 at% ^{134}Xe, and found to compress to a radius that corresponded to a P0 of 73 μm, with a P2 asymmetry of 22%. The design for the nitrogen doped capsule is not the same as N170112-004, but for the purpose of an order of magnitude estimate of dopant level needed, this radius provides a reasonable estimate. To error on the conservative side, we assume a total yield of 10^{15} for the nitrogen/argon doped capsule, although our 2D xRAGE simulations predict a yield of 7.2×10^{15}. Thus, our spherical uniformly burning capsule estimate for the production of ^{13}N is that 2×10^{12} dopant ^{14}N atoms are required. For ^{41}Ar, 2.5×10^{13} ^{40}Ar atoms are required. To be further conservative, we double the spherical estimate, and suggest that 4×10^{12} ^{14}N dopant atoms and 5×10^{13} ^{40}Ar atoms are required.

The capsule design for our upcoming shot in January 2022 involves 4×10^{18} DT atoms. Thus, nitrogen and argon dopant fills at the 0.05 at% level should be more than adequate to meet the needs for the RAGS measurement.

References

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